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The rich life of light rising spheres

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It is now well established that the straight path of gravity-driven rigid spheres falling or rising in a weakly viscous fluid becomes unstable beyond a critical value of the so-called Archimedes number, Ar, which is a Reynolds number built on the gravitational velocity scale $((m^*-1)gd)^{1/2}$ (d is the sphere diameter and m* its relative density). Various styles of non-straight paths have been reported so far: steady or oscillating oblique, planar zigzags, three-dimensional chaotic, etc. However despite careful computations (Jenny, Dusek & Bouchet 2004) and experiments (Horowitz & Williamson 2010), there is currently no consensus as regards the possible critical density ratio below which significant departures from straight (vertical or oblique) path is observed. The only consensus to date seems that the drag coefficient increases significantly beyond its standard value for "sufficiently" small m* (Ern et al. 2012). To revisit this question, we carried out a detailed DNS study focused on rising spheres ($m^*<1$) in the range $150 \leq Ar \leq 350$, following the computational approach developed by Mougin & Magnaudet (2002). We improved this approach by accounting explicitly for transient viscous effects induced by the sphere translational and rotational accelerations, as they control the time rate-of-change of the sphere rotation rate in the limit of small m*. Extensive tests were also performed to ensure grid independence and minimize spurious grid-induced anisotropy effects to which the path was found to be highly sensitive, the sphere being a point-symmetric body. No-straight paths with significant horizontal excursions were observed throughout the whole range of m*. We recovered the various types of paths reported in the literature but also observed other styles such as intermittent zigzagging/oblique in which the average vertical along which the sphere rises changes from time to time. The nonlinearity of the zigzags was also found to increase significantly for very light spheres (typically $m^* \leq 0.1$), owing to the development of secondary path oscillations associated with higher frequencies. A significant increase of the drag coefficient, up to 15% beyond the standard drag curve, was noticed as soon as the sphere experiences significant lateral accelerations.